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Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Space Computing Systems Validation Challenges

ITI Workshop
Coordinated Science Laboratory
University of Illinois

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Introduction

- **Challenges of Spaceborne Computing Systems**
  - **The Good, The Bad, The Ugly**
- **Validation Approaches**
  - **Past, Present, Future**
- **Some Thoughts**

1958
First U.S. satellite

Explorer 1

The Good: Small, Simple, Robust – It Worked!

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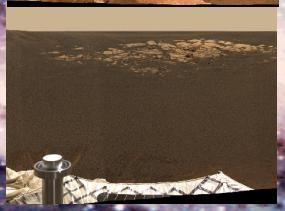
Over 50 NASA Missions Currently Flying

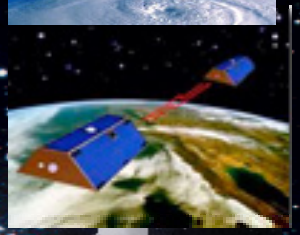
Spitzer studying stars and galaxies in the infrared

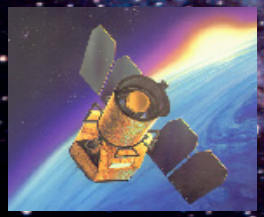
Ulysses studying the sun



Mars Odyssey, rovers "Spirit" and "Opportunity" studying Mars

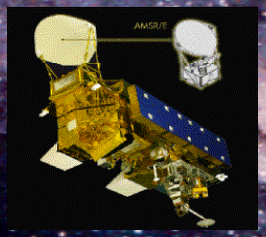
Cassini studying Saturn



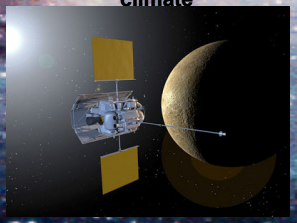


GALEX surveying galaxies in the ultraviolet

CALIPSO studying Earth's climate



Aqua studying Earth's oceans



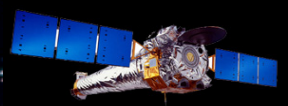
MESSENGER on its way to Mercury

Two Voyagers on an interstellar

Aura studying Earth's atmosphere

Hubble studying the universe

QuikScat, Jason 1, CloudSat, and GRACE (plus ASTER, MISR, AIRS, MLS and TES instruments) monitoring Earth.



Chandra studying the x-ray universe

New Horizons on its way to Pluto

The Bad: Complex Expensive Systems, Severe Environments, Remote Locations, No Second Chances – Sometimes They Work,… Sometimes Not So Good

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The Ugly
(Significantly more severe than Earth orbit)

- **High Radiation**
  - Mrads and GeV
- **Extreme Temperatures**
  - -270 deg F on Europa to >900 deg F on Venus,
  - >1000 cycles of 100 deg on MER (Mars)
- **Vibration**
  - Launch, Planetary Entry, Descent, Landing, Roving, Quakes, Impacts, Turbulence
- **Power**
  - <100W (typically <50W) available for computing
- **Mass**
  - < 10kg vailable for computing
- **Low Error Tolerance**
  - Navigation, Automated Operations, Communication, Deployments

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More Ugliness

- One-Off Systems in a Cost/Schedule Constrained Environment
- Hardware:
  - Theory: Legacy, Rad Hard, Fully Qualified, Thoroughly Characterized, Tested and Validated
  - Reality: Complex COTS and Custom Parts, Minimal Characterization and Test Possible (Current DRAMs have upwards of 60 modes of operation)
- Software:
  - Theory: Software Fixes All Ills
  - Realty: Not Available Till After Launch, Usually More Complex Than Can Be Handled By Current T&V Technologies, Limited Visibility into COTS Software
- Often Can't Test Final System Until It's Flown
  - Realistic Space/Mission Environment Unavailable On The Ground
  - Software Not Available Until After Launch
- Next Gen Systems Need COTS Multicore Machines, Low Power, High Performance Parallel Processing: Science Data Processing (not just compression) and Autonomy (not just automation)

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Flight and Ground Software Anomalies
(It's Not Getting Any Better!)

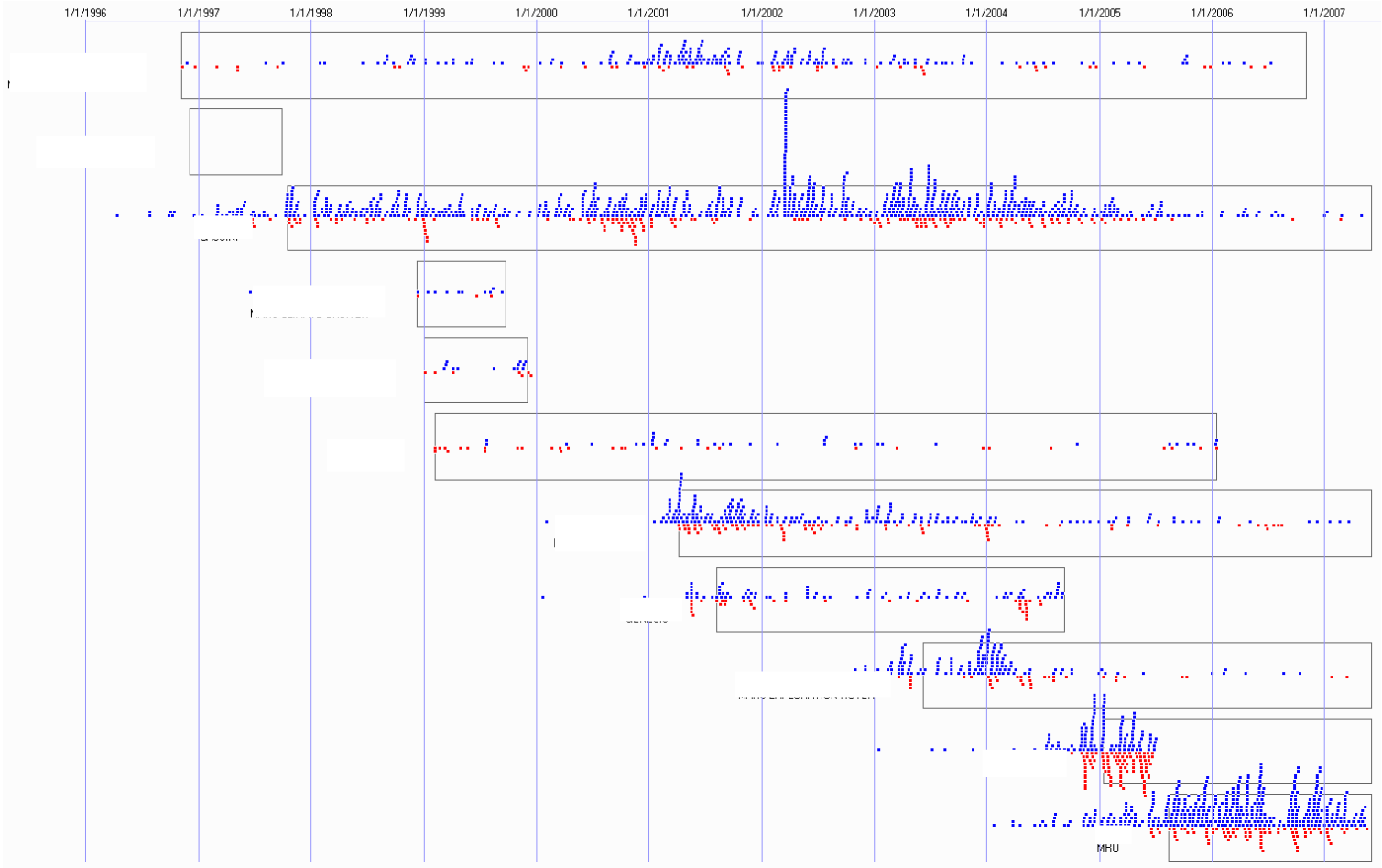

Chart Courtesy of: Martin Feather, Al Nikora

Some Examples

- **Software:**
  - **Mars Climate Orbiter (Mars '98) – km vs miles**
  - **MER – buffer overflow**
  - **Arianne V – 64b->16b conversion register overflow**
  - **Cassini – command sequencer buffer size and command concatenation/reconstitution**

- **Hardware:**
  - **Galileo Antenna Deployment**
  - **Cassini Memory**
  - **ST5 Memory**
  - **MER FPGAs**

The REALY Ugly

- **Ground Based COTS Systems Are Not Immune**
  - **Neutron Induced SEU's reported at 250nm node**
  - **Alpha Induced SEUs reported at 65nm node**
  - **COTS Supercomputers in benign lab environments require fault tolerance due to MTTF of SOTA COTS components**
  - **Hardware Companies are Incorporating Fault Tolerance Into Their Processors and Support Chips To Reduce But Not Eliminate The Problem**
  - **Some Hardware Companies are Starting To Look At Hardness By Design Techniques (radiation, noise, thermal, mfg defects,…)**
  - **The Issue Is No Longer "will it upset?", But "what upset rate won't be noticed"**
  - **COTS Software – Unreliable and Opaque**
  - **Current Software Schedules/Budgets/Failure Rates are Unacceptable**
  - **System Failures are Endemic**
    - **Accepted As Normal and Unavoidable**

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Validation Approaches Past

- Gross level radiation testing of critical components
- Standard Shake & Bake of Subsystems & Systems
- Unit and Build Testing of Software
  - Simple RTOS used as a ground commanded sequencer
  - Extensive testing on ground based simulator
  - Success oriented testing of normal ops
- Extensive code walk through, and testing on simulators of operational sequences
  - Success oriented testing (does it work in expected scenarios)
- Extensive operator and engineer participation in every aspect of operation, close monitoring of sequence execution, quick human reaction to problems
- Bottom line:
  - Simplify system, test spec'd scenarios, count on human ingenuity and hope for the best

Validation Approaches Present

- **Similar to Past With Some Additions:**
  - **Occasional Board Level Hardware Rad Test Using Custom Test Software**
  - **Occasional Software/System Model Based Validation (eg. Spin)**
  - **Occasional Software/System Formal Methods Based Validation**

BUT

  - **Model and Formal Methods Based Validation Difficult With Large Complex Systems**
  - **Still Require Significant Engineer Involvement in Operations**
  - **Still Find Errors in System and Application Codes, and Unanticipated Hardware Faults during mission ops**

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Thoughts On Validation Approaches For Future Systems

- ***Assertion*: The Validation Problem Can Not Be Solved in the V&V Domain**
  - **The Fundamental Issue is Minimization, Knowledge and Control of State Space**
  - **To Achieve System Validation, The State Space Must Be Constrained**
  - **Once Constraints Are Placed On State Space, Automated Methods Can Be Applied**

- **Need a New Design/Test/V&V Paradigm (here's one possibility)**
  - **Understand The Problem:**
    - **Extensive characterization of detailed component fault set/rates**
    - **Fault/Error propagation model**
  - **Fault Tolerance built into all systems/hardware/software**
    - **Supported by models, tools and automation at the design level**
  - **Automated formal methods and model based validation of code segments and system operational modes to the extent possible.**
  - **Sequencer Based Software Design/Implementation**
    - **Standardized constructs and implementation rules**
    - **Standardized representations and abstractions**
  - **Software JTAG Bus**
  - **Automated Exhaustive Test Vector Generation and Test Execution**
    - **Fault Injection Testing Using Fault/Error Models**
  - **Board level system radiation (and other environmental stresses) testing with operational software and realistic worst case system operational scenarios**
  - **Random Unstructured System Test in realistic (simulated) system environment**